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I, LEANNE MYNOTT, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PQ 3088 for a patent by AEGIS PTY LTD filed on 27 September 1999.

WITNESS my hand this
Twenty-fourth day of August 2000

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PROVISIONAL SPECIFICATION

for the invention entitled:

"Locating Device"

The invention is described in the following statement:

LOCATING DEVICE

This invention relates to locating device for determining location of a buried cable, and a locating device for determining the position of a fault in a cable.

Buried underground cables and pipes (often referred to as services) sometimes develop faults and are not always clearly marked on plans, especially if they were not recently installed. As a result, there are often two different requirements for fault or service location.

One requirement is to locate the buried service. This function is often referred to as tracing. It is possible to do this by placing an electrical signal on the service and to detect this by a suitable mobile receiver, the detected signal strength being used to determine the location of the service. By using different combinations of antennas one may obtain different responses:

a peak response shows maximum signal strength when directly over the service. This is obtained from an antenna that picks up the horizontal component of the magnetic field created when current flows through the underground service;

a null response shows a sharp drop in signal level when directly over the service. This is obtained from an antenna that picks up the vertical component of the magnetic field created when current flows through the underground service. This gives a more easily identified sign that the service is directly below. By comparing the phase of the peak and null response, it is possible to obtain an indication of the direction to the cable. This speeds up the tracing process. By using more than one peak antenna, it is possible to narrow the peak to give better definition of where the underground service is, measure the actual current flow in the cable, measure the depth of the cable or reduce susceptibility to signals from overhead eg. Overhead power lines. By using arrays of antennas, one may determine in three dimensions the position of the service.

A second requirement is to locate faults in the underground service. A precise fault location is desirable because it reduces the amount of digging required to repair the cable. Underground cables can develop a number of different faults. Some examples are:

- open circuit;
- short circuit to another conductor;

- short circuit to the shield; and
- short circuit to the ground, also known as a sheath fault because the cable sheath has been breached.

A fault of primary interest is the sheath fault. One common method of detecting the location of this is to use a ground probe to search for maximum signal strength. This is effective because the ground is a volume conductor and the fault current is denser near the fault than it is as one moves further away. The maximum current point will be nearest the fault. One drawback of this method is that it is not possible to tell the direction to the fault and one must hunt to find whether one is moving closer to the fault or further from it. It is possible to address this limitation by various methods.

One method employs a large DC voltage to produce a deflection on a DC voltmeter. The direction of the deflection shows the direction to the fault, as the current flow is always away from the fault. The disadvantages of this method are that there are often DC current offsets in the soil which can give false readings and most cable connected equipment may not be tolerant of high DC voltage levels.

Another method is to use a very large voltage pulse to produce a deflection on a meter. The direction of the deflection shows the direction to the fault. The disadvantages if this method are that it is unreliable in wet soil, and the voltage pulse can damage the cable insulation or connected devices. The advantage over the DC voltage method is that it reduces problems due to local DC or very low frequency AC currents in the soil.

A further method involves adding a higher frequency carrier signal which is picked up by an antenna. This is processed and compared to the signal in the ground to determine the polarity of the signal in the ground. This method has the advantage that the ground signal can be a continuous AC signal. The drawback is that one must keep the receiving device locked to the cable frequency, and higher frequencies have a lower range.

~~Another method uses multiple harmonically related frequencies simultaneously to try~~

and calculate the direction to the fault. The phase relationships of the signals are compared and the sign of the deviation between them is used to determine the direction to the fault. The sign of the phase deviation is equal to the polarity of the signal and hence the direction can be calculated. The advantages of this method are that it lessens the problems with DC signals, and also overcomes the need to keep the receiver locked to an external signal on the cable. The disadvantage is that errors in signal phase caused by noise and mains switching transients can produce incorrect results, effectively pointing the user of the device in the wrong direction.

Another problem with cable tracing equipment is known as ghosting. This is where a false direction indication is given once one travels a sufficient distance away from the cable. This can be caused by phase shift artefacts in ferrite antennas or by interaction between the antennas where the weaker signal vector is interfered with by fields from the stronger signal vector. The likelihood of occurrence of ghosting may be reduced by reducing the lateral range of the instrument so it never operates in the zone that could cause ghosting due to antenna interactions. Another source of ghosting, real world coupling of the signal onto other conductors, cannot be eliminated by reducing the range.

In one aspect, the invention provides a device for locating an underground cable on which cable is placed an electrical signal, the device having first and second and antennae, these being disposed in an angular disposition one with respect to the other, and a detector means for detecting electrical signal arising from electromagnetic radiation due to the signal applied to the cable, the antennae being disposed such that when the device is level, the antennae extend at angles from lower locations in upwardly convergent relationship, the angle between each antenna and the horizontal being greater than zero and less than 90°, such as 20° to 60°, more preferably 30° to 40°. Preferably, the antennae have helical windings on respective central axes. Preferably, too, the windings are on ferrite cores.

Preferably, the locating device incorporates means for selecting the one of said antennae, based on the strength of received signals at the antennae.

The invention also provides a device for locating an underground cable on which cable

is placed an electrical signal, using a device having first and second and antennae, these being disposed in an angular disposition one with respect to the other, comprising disposing the antennae so that these extend at angles from lower locations in upwardly convergent relationship, the angle between each antenna and the horizontal being greater than zero and less than 90°, such as 20° to 60°, more preferably 30° to 40°, and detecting electrical signal arising from electromagnetic radiation due to the signal applied to the cable.

The invention also provides a device for determining location of a fault in an underground cable causing an earth leakage path from an internal conductor to earth at the location of the fault whereby, when signal is applied to the conductor, earth leakage signal flows between the earth and conductor at the location of the fault, wherein the applied signal is a multi-frequency signal having at least two frequency components, the device having probe means positionable to receive the earth leakage signal, and means for rectifying a first component of the earth leakage signal corresponding to one said frequency component of said applied signal and multiplying the first component of the earth leakage signal with a second multiplying of the earth leakage signal corresponding to another frequency component of the applied signal, such that the result of said multiplication then represents the direction from the device to the fault. The multiplication may be effected as an array multiplication of sets of time-spaced samples of the first and second components of the earth leakage signal.

Preferably, the device incorporates means for detecting and removing artifacts due to external interference such as switching transients.

Preferably, the device incorporates means for determining a confidence indication, indicating a degree of reliability of said result. The last-mentioned means may operate to determine said confidence indication by applying selected criteria to said result, such as the ratio between maximum positive and negative excursions thereof, and/or the signal-to-noise ratio of the detected signal and/or the absolute signal strength of the detected signal.

Some or all of signal processing may be effected digitally, under control of suitable software. ~~The invention also provides a method for determining location of a fault in an~~

underground cable, wherein signal is applied to the cable to cause generation of an earth leakage signal from an internal conductor of the cable to earth, at the location of the fault, the applied signal being a multi-frequency signal having at least two frequency components, receiving the earth leakage signal, and rectifying a first component of the earth leakage signal corresponding to one frequency component of said applied signal and multiplying the rectified first component of the earth leakage signal with a second frequency component of the earth leakage signal corresponding to another said frequency component of the applied signal, such that the result of said multiplying then represents the direction from the device to the fault. The multiplication may be effected as an array multiplication of sets of time-spaced samples of the first and second components of the earth leakage signal.

The invention is further described, by way of example only, with reference to the accompanying drawings, in which:

Figures 1 and 2 are diagrams illustrating general principles of operation of a cable location detector;

Figures 3(a) and 3(b) illustrate arrangements of angled antennae in accordance with the invention;

Figures 4 and 5 illustrate general principles of fault location in a cable;

Figure 6 is a waveform diagram showing waveforms applied to a cable for fault location detection in accordance with the invention;

Figure 7 is a diagram of a fault location device constructed in accordance with the invention;

Figure 8 is a waveform diagram illustrating signal manipulations effected in accordance with the invention;

Figures 9, 10 and 11 are diagrams illustrating operation of the fault locating device in accordance with the invention; and

Figures 12 to 15 are flow charts describing software manipulation effected in operation of a fault locating device constructed in accordance with the invention.

A compact form of antenna for use in tracing uses a ferrite rod core with windings on a bobbin, or on an insulator around the core. These types of antennas provide good on axis sensitivity in a compact shape, but lose sensitivity when the magnetic field vector is not parallel to the ferrite core. Indeed, when the external magnet field is perpendicular to the ferrite core the sensitivity is zero. The loss of sensitivity as the external magnetic field become perpendicular to the antenna limits the effective horizontal range of the instrument.

To obtain an indication of the direction to a cable, two antennas may be used. One may be positioned in the vertical plane and referred to as a null antenna because the signal becomes null as the antenna passes over the cable. The second antenna may then be a horizontal antenna and referred to as the peak antenna. This antenna's output peaks as it passes over the cable.

As the null antenna passes over the cable, the signal dips to zero and as the antenna continues to move the signal level increases but is of opposite phase. The peak antenna phase does not change during this move so the change of relative phase between the peak and null antennas can be used to determine the direction to the cable. Figure 1 illustrates this. In Figure 1, the electromagnetic field around a cable at the location 12 shown is indicated by arrow 14. The horizontal antenna 16 and vertical antenna 18 are shown at three different locations, locations (a) and (c) to opposite lateral sides of the cable, and location (b), directly above the cable.

The following explanation is expressed in terms most applicable to DC, current but the same relative phase relationships exist for AC currents.

~~On the left hand side (location (a)), the field rotates upward and will induce a positive~~

voltage into the vertical 18 coil and also into the horizontal coil 16. On the right hand side (location (c)), the field flows downward and will produce a negative voltage in the vertical coil 18, but the horizontal coil 16 will still have a positive voltage. Over the cable, the vertical antenna 18 has no signal but the horizontal antenna 16 is at maximum signal.

Figure 2 illustrates the effect as the antenna 16 moves to locations (a), (b), (c), (d), (e) respectively above and progressively horizontally distance from the cable. Firstly, as the distance from the antenna 16 to the cable increases, the signal level falls. This is independent of the antenna orientation. Secondly, the angle between the antenna and the magnetic field from the current flowing in the cable changes from zero degrees to nearly 90 degrees. There are thus two sources of reduced signal in the antenna as one moves further from the cable, the increasing distance to the cable and the change in antenna orientation relative to the cable. The further from the cable the antenna is, the more significant is the received signal level reduction due to the change of angle.

For a cable buried 600 mm underground and an antenna held 400 mm above the ground, the empirically determined point where the signal is no longer reliably detectable is at a lateral distance of about 3.5 m from the cable. This is at an angle of 74 degrees between the axis of the ferrite and the vector of the magnetic field. This was determined for a ferrite antenna of the following construction:

Ferrite rod:	Neosid, 100 mm x 9.5 mm, Material F8 ($\mu r = 1200$)	
Winding:	Enamelled copper wire:	0.315 mm, grade 1
	Turns:	1296
	Inductance (assembled):	≈ 200uH
	Resistance:	≈ 20Ω

It will be observed that there are altogether four problems:

- the signal level falls with distance from the cable;
- the signal level falls as the cosine of the increasing angle between the ferrite rod ~~and the magnetic field vector;~~

- the small signal is prone to phase shift errors which can cause the direction to cable indication to point in the wrong direction; and
- interaction between the fields in the antenna can cause ghosting, or false direction indication.

It may appear that these limitations, which reduce the effective lateral range of the antenna, could be overcome by the following expedients:

- holding the antenna further off the ground to reduce the cosine angle signal reduction;
- holding the antenna on an angle to reduce the cosine angle signal reduction; and
- reducing sensitivity, accepting the resultant small lateral range.

In practice, these options are not satisfactory. When tracing a cable, one often does not know where it is. So it is not possible to surely angle the antenna in the correct direction. Once the cable is found, it would be possible to demonstrate that one may walk away from it and obtain a good range, but this is not readily possible when first seeking the cable. Also, a small lateral range is unhelpful when searching for the location of a cable.

The problems mentioned may also be addressed by using more than one antenna. Since angling the antenna reduces the cosine error, the antenna may be angled. However, the tilt to be used is different depending on the direction of the cable from the antenna. This is illustrated in Figures 3(a) and 3(b).

For the above case shown in Figure 3(a), the antenna 16 is angled at 45 degrees to the horizontal and is to the left of the cable 14. The cosine angle reduction may exhibit a maximum of 30% in this case, provided the antenna is always to the left of the cable. Once the antenna crosses over to the right of the cable, the benefits are quickly lost and the range is poor on that side, and incorrect results are generated if one goes far enough to the right.

To overcome this, two antennas are, in accordance with the principles of one ~~embodiment of the invention used. The antennae 16(a), 16(b) of the locating device of the~~

invention are shown in Figure 3(b) arranged with complementary angles.

When the antenna pair are to the left of the cable 14, as viewed in Figure 3(b), the leftmost antenna should be used. When the antenna pair are to the right of the cable, the rightmost antenna should be used. When directly over the cable, either can be used. By examining the received signal strength at each antenna, the correct one can be selected and the horizontal range may be greatly improved, being only limited now by the fall off in signal strength due to distance from the cable. This selection of the antennae to be used may be effected automatically by the locating device.

Another advantage is that the likelihood of ghosting due to antenna interaction is also greatly reduced. Because of the angling of the antennas, the field vector in the better aligned antenna is always comparable to that in the null antenna and so the interaction of the null antenna field, which can cause ghosting when the peak antenna is horizontal, may also be reduced.

The dual antenna arrangement of Figure 3(b) uses 45 degrees as the angle to the horizontal to hold each antenna at. This is the optimal angle for a single antenna, but for a pair of antennas it is desirable to use a slightly smaller angle. This is because the signal strength from each antenna begins to become equal again as the pair become nearly horizontally disposed to the cable at the extremes of the lateral range. To prevent this, a small reduction in angle is required. An angle of 30 to 40 degrees is likely to prove optimal for most applications.

If more angled peak antennas are used, ie at least three, then the direction to the cable could be shown as a compass-like reading rather than just left or right.

Either way, the above are only examples and the principle of using one or more angled antennas is not restricted to any particular angle or any particular number of antennas.

Figure 4 is a generic diagram illustrating a method of sheath fault location using a ~~transmitter and a ground probe based receiver~~

A signal is placed on the cable 14 at a convenient access point by use of a generator 20. The return path for the signal is ground. The actual conductor used is the one with the sheath fault on it, otherwise there would be no return current. The fault is represented by an impedance 22 to ground and located at location 20 along the cable. In practice, the ground return path is complex and depends on the type of soil, moisture content, depth of cable and the presence of other buried conductors such as metal water pipes.

A ground probe 24, represented as a volt meter, is used to measure the voltage potential in the ground to determine the direction from the ground probe to the fault. This has two ground probe elements 24a, 24b which are positioned in spaced relationship in the ground, the probe if necessary being moved to various successive ground locations at which the probes are entered into the ground, and meter readings taken at the voltmeter.

Near to the fault, the ground currents branch out from the fault. Because of this, the ground probe can correctly identify the direction to the fault from either side of the fault. Directly over the fault, there is no signal at all and it is by determining the location of the probe at which this result ensues that the location 20 of the fault is determined. This is illustrated in Figure 5 where the currents branching out from cable 14 at the fault are illustrated diagrammatically by arrows 26, and the polarities of detected signal at the voltmeter when positioned along the length of the cable, but to opposite sides of the fault is shown as being relatively reversed. There is no detected signal when the voltmeter is positioned adjacent the fault, and this is how the fault is located.

To reduce losses due to cable capacitance, lower frequencies are preferred. But frequencies in the normal operating range of the cable may cause cross talk and interference to other cables. As a result, frequencies below 300Hz or above 3.4KHz may be preferred. Frequencies below 300Hz are however close to the harmonics and fundamentals of power frequency transmission equipment. As a result, signals well below 50/60Hz may be most preferable.

~~There are three basic methods that might be used to show the direction to fault:~~

- DC shift;
- cable carrier and/or locked carrier reference; and
- phase deviation.

The DC shift method involves either placing a large DC voltage on the cable or using a large pseudo impulse. The latter is preferable because it is less susceptible to local DC and low frequency AC currents, but both methods suffer from limited range in the wet and the possibility of damaging the cable.

The method cable carrier and/or locked carrier reference involves locking an on-board reference to the transmitter. This can be most easily achieved by sending a carrier signal down the same cable and picking it up with an antenna. Alternatively, a radio based carrier system could be used. Another method is to lock the receiver to the transmitter and hold the lock using a very low drift oscillator. In practice, a low drift oscillator locked to a cable borne signal may be more easily achieved. The disadvantage is that cable borne signal must be a high enough frequency to be readily picked up by a compact antenna and this normally brings it into or above the voice band. Signals in the voice band are not preferred by telecommunications carriers and higher frequencies are harder to keep phase aligned due to capacitive effects in the cable.

The phase deviation method involves using more than one frequency and measuring the direction of phase deviation between the two signals. If the direction of deviation is one polarity, then the fault lies in one direction, otherwise it lies in the other. These methods suffer from the fact that phase distortion or noise can cause erroneous results, even reversing the direction. Lower frequencies are preferred to improve range and reduce phase distortion due to capacitive effects, but because of the close proximity to mains power frequencies and their harmonics, substantial filtering is required. Filters are difficult to make phase shift free, and high Q band pass filters can ring in the presence of noise and switching transients, giving rise to false detections and incorrect direction results. At the very least, careful phase alignment is required.

~~In all of the above cases, it is difficult to provide high confidence that the user will~~

correctly interpret the results and know when to ignore spurious readings.

The DC shift method involving high voltage pseudo impulses requires the operator to ignore slowly drifting meter movements, and to recognise a characteristic flicker due to the voltage spike. Audible feedback from the transmitter also helps for nearby faults. Unfortunately once the signal level drops, it is difficult for the operator to distinguish the random noise from the signal which is then likely to be minuscule.

The cable carrier systems and phase deviation systems have a similar difficulty. Once the signal level falls, the meter indicator can move sporadically in either direction, and it is hard for the user to objectively interpret the result.

Some systems attempt to also give the user an idea of the signal level, but this can also be misleading. A weak signal in a quiet area may be much more usable than a strong signal in a very noisy area such as near a mains power substation or railway line with track circuits energised to detect passing trains. Systems which ignore signals once the level falls sacrifice range.

An embodiment of the invention which addresses these limitations is now described. This uses a transmitter which is connected to the cable and applies to it a multi-frequency signal. In this exemplary embodiment the two frequency components are applied, there basis of frequency 8 Hz and 16 Hz respectively.

Figure 6 shows the waveform produced at the transmitter and its 8Hz and 16Hz components. Here, the amplitude of the final composite 8Hz+16Hz waveform is kept to below 150V Peak to Ground which will not harm normal telephony cable insulation nor most connected devices. The waveform is a simple mix of two frequencies. A factor of 2 is used for the two frequencies. Other factors could be used but a more complex function than taking the absolute value of the lower frequency would be required and the repetition interval would increase which would slow down the measurement rate. Also, if higher factors are used then ~~it is much harder to filter out the noise and interference signals, especially if you are operating~~

below the normal mains power frequencies. If ratios below 2 are used, eg. 3:2, then the filtering problems are avoided but more complex functions and longer repetition intervals are again required. Choice may best be based on a balance between filtering, ambient signals and the time it takes to collect the sample. At 8Hz it takes 125msecs for a full wavelength, at 4Hz it takes 250msecs and at 0.1Hz excessively long processing times may result.

The form of the transmitter waveform is preferably relatively simple, and largely non-critical, as described. This is advantageous, because the signal is transmitted through ground which is a noisy and unpredictable medium. Special features may become distorted and a complex spectral or phase based pattern may be rendered unrecognisable, especially as the distance from the fault to the ground probe increases.

Figure 7 shows a ground probe 32 useful in practising the invention. This has a differential amplifier 34, used to amplify the voltage difference between ground probe elements 36. Fifth order low pass and high pass filters 38, 40 are used to remove out of band noise. These are set at 24Hz and 4Hz respectively. A notch filter 42 is also used to remove mains power primary frequencies, at for example either 50Hz or 60Hz. The resulting signal is amplified at amplifier 44 and fed through two band pass filters 46, 48 to isolate the 8Hz and 16Hz signal components. A delay equaliser (not shown) is used to compensate for phase shift between the signals as a result of the processing.

Once the 8Hz and 16Hz signals are acquired, they are processed by a processor 50.

In order to obtain polarity information from the so extracted waveforms without using phase deviation and its inherent problems with noise immunity, the 8Hz signal is first rectified. Next it is array multiplied with the 16Hz signal.

The multiplication is element-by-element in the following manner:

$$[a_1,a_2,a_3,a_4...]*[b_1,b_2,b_3,b_4...] = [a_1*b_1,a_2*b_2,a_3*b_3,a_4*b_4...]$$

where a_n and b_n are respective time spaced samples of the rectified 8Hz signal and the 16Hz signal.

The resulting signal shows a reproducible characteristic with the mean offset being in the direction of the 16Hz signal peak which is closest to the 8Hz signal peak. This characteristic may be stable with nearly 90 degrees of phase shift in the 16Hz signal. This is a substantial improvement over the phase deviation methods. Figure 8 illustrates these manipulations.

It is noted that there is an obvious ratio between the maximum negative excursion and the maximum positive excursion. This is at around 1:4. There is also a natural ratio between the mean and the maximum positive excursion. This is around 1:6. By applying these metrics to the acquired signal it is possible to deduce the likelihood that the signal has only good components.

Also, if a switching transient does occur, there will be expected to be a substantial discrepancy in the metrics. If all signals that exceed the peak to mean ratio are clipped, and the metric re-run, then the influence of the positive peak will be expected to be reduced and no longer cause an excessive contribution to the mean calculation.

Figure 9 shows the above-mentioned rectified and array multiplied signal in the case where this includes a large interfering peak.

The mean in this case is very slightly negative, although the mean for just the signal components that are part of the transmitted waveform would be expected to be positive. Figure 10 shows the signal after the metric has been run and the peak excursions clipped. As can be seen, the mean is now positive, and the effect of the interference has been overcome.

It is also possible to use the metric to eliminate results that are so heavily distorted that they cannot be successfully corrected. This lessens the problem of giving the operator a misleading result which the operator must otherwise recognise and ignore. The unit may do that ~~for the operator, and at least substantially avoid providing spurious data.~~

Because the mean of the array multiplied signal is known, both before and after the clipping, the ratio of these means can be used to gain confidence in the direction indication. If the ratio is close to one, then the original signal conformed fairly well to the target metric and is likely to be good. If the ratio is high, then confidence is reduced as the original signal did not fit the profile very well.

In addition, the ratio of the peak to the mean is also well defined. If this is within allowed limits before and after the clipping then confidence is high. If the ratio was outside the limits before clipping but came back into line after clipping, then confidence is less. If the ratio is poor for both cases then confidence is low.

For example, start with confidence = 100%.

1. If the peak to mean ratio before clipping was more than 20, and the target was 6, then reduce confidence by 50%, otherwise if the ratio was 10 then reduce confidence by 25%.
2. Now clip the signal. If the new peak on mean ratio is more than 20, then half the confidence, otherwise if it is more than 10, then reduce confidence to ¾ of the previous amount.
3. Now divide the peak on mean ratio before clipping by the peak on mean ratio after clipping. If this ratio is more than 3 then reduce confidence by ½, else if it is greater than 2, then reduce confidence to ¾ of the previous value.

At the end of this, a final confidence interval is reached. For a good clean signal, confidence will be 100%. This is as expected. If the signal was clean enough after clipping but a bit dirty beforehand, confidence will be 75%, and so on. This process can be extended to any number of steps depending on the complexity of the metric. The exemplary thresholds given here have been found satisfactory for the waveform and metric used as an example of the method. Once the confidence falls to a low enough level, ie < 33%, then declaring results may be stopped as the results are almost certainly unreliable.

Although a specific implementation is described here in order to properly explain the invention, other enhancements are also possible.

The transmitted power can be increased without increasing the peak voltage excursion of the waveform by altering the phase relationships between the waveforms. Figure 11 illustrates this. As can be seen, the peak excursion of the second waveform is symmetrical at about +/- 1.8, whereas the initial waveform has a peak positive excursion of 2. Both have a DC average of zero. The receiver must realign the phases again to ensure the metrics still work but this is simple to do.

The example implementation here employs a mixture of analog and digital processing. The selection of which part of the process is done in which way is a matter of design choice. Metrics may be done using analog circuitry, and the filtering could also be done digitally with A/D sampling earlier in the chain. The choice of signal processing method is not critical to the implementation of the improved method for finding the sheath fault location.

Although this implementation only uses two frequencies, it is possible to extend the methods used to multiple frequencies and similar metrics across these frequencies in groups of two or more at a time.

In additional to measuring basic waveform metrics such as peak to mean ratio, other more complex metrics can be applied, such as least squares fit to a target waveform. The specific choice of metrics is a compromise between ease of computation and likelihood that error detection will be improved by adding the metric. The examples given here have been demonstrated to work satisfactory for a ground based sheath fault locator.

Averaging a number of results can further reduce spurious readings. The results can either be averaged when initially collected or else averaged after processing. There are some advantages of post processing averaging as only the better results get included in the average. Use of spurious results should obviously be avoided. The confidence factor can also be used to create a weighted average where the higher confidence results have more bearing on the final result than the lower confidence results.

Figures 12 to 14 are flow charts illustrating software executed steps in an exemplary

device constructed in accordance with the invention.

Figure 12 shows steps in acquiring data samples of received signal. In samples are acquired at a 256 Hz sample rate, 64 samples being acquired for each overall program execution. This provides 250 mseconds of data or two complete cycles of the 8 Hz waveform.

Execution of the data acquisition steps as illustrated in Figure 12 begins by setting a timer for 256 Hz, at step 102, followed by clearing of buffers and a counter at steps 104, 106. Thereafter at step 108, the program awaits the timer, and then reads the 8 Hz and then the 16 Hz signal at steps 110, 112. At the next step, step 114, a counter is incremented by one step and at the following step 116 a determination is made as to whether the count incremented at step 114 has reached 64. If it has not reached 64, steps 108 through to 116 are repeated, this being so repeated until the count reaches 64 after which, at step 118 acquisition is complete.

In the steps illustrated at Figure 13, the 64 data points for each of the 8 and 16 Hz signals as acquired by the process steps shown in Figure 12 are processed. First, at steps 120, 122, 124, mean, and counter registers peak are cleared. Then, for the first data point acquired, the multiplication of the absolute value of the 8 Hz signal together with the 16 Hz signal is computed, at step 126, to which a mean figure, comprising a previous mean, plus the result of step 126 is computed, this being executed at step 128. After this, at step 130, comparison of the absolute value of the result of step 126 is made with that of a peak value (initially zero) and if that absolute value is greater than the peak, the peak is, at step 132, updated to reflect the absolute value of the result of step 126. Next, a counter initially set to zero is incremented one step, this being effected at step 134. Then, at step 136, it is determined whether the counter has reached a stored count of 64. If it has not, steps 126 through 136 are repeated, this repeating being effected until the count reaches 64 after which at step 138 there is computed a mean value representing the mean accumulated by the repeated executions of step 128 divided by 64. After that, at step 140, signal processing is judged complete.

Figure 14 shows program steps for determining a metrics calculation. First, at step 150, the ratio of the peak value to the mean value as computed at steps 132 and 138 is computed.

Then, at step 152, an expected peak value is set as the absolute value of the mean computed at step 138 multiplied by six. The program execution of this part of the program is completed after this, at step 154.

Figure 15 illustrates steps in effecting clipping of results according to expected peak result. At step 160, a counter is cleared. Then, at step 162, a comparison is made between the absolute value of the result, as computed at step 130, and an expected peak value. If the absolute value of the result is greater than the expected peak, it is then determined whether the result value is less than zero. If not, the result is set to the expected peak, at step 166; otherwise it is set to the negative of the expected peak step 177 (described later). If, at step 162, the absolute value of the result is not greater than the expected peak, steps 164 and 166 are skipped and the program moves to step 168. Program execution precedes from step 166 or step 177 also to step 168, which is to increment the counter. At step 170, it is determined whether the count in the counter has reached 64. If not, program steps 162, and if appropriate one or more of steps 164, 166 and 172, are repeated as before described. Otherwise, results clipping is completed at step 174.

Figure 16 illustrates program steps in computing confidence results, including the steps described in the flow charts of Figures 12, 13, 14 and 15.

Firstly, at steps 180, 182 and 184, the steps illustrated respectively by the flow charts of Figures 12, 13 and 14 are effected. At steps 186, 188 mean #1 and ratio #1 values are set to the mean and ratio value respectively, as computed previously, and results clipping then occurs at step 190, in accordance with the flow diagram of Figure 15. Subsequently, at steps 192, 194 mean #2 and ratio #2 are set to the resultant values of mean and ratio determined at step 190. Then, at step 196, a confidence value is set to 100% and, subsequently, at step 198, a determination is made as to whether the value of ratio #1 is greater than 10. If it is greater, at step 200 it is determined whether ratio #1 exceeds 20. If so, the confidence value is set to confidence *.05 at step 202, after which processing proceeds to step 204 later described. In the event that the result of the comparison of step 198 should be that the ratio #1 is not greater than 10, program execution likewise proceeds at once to step 204. If, at step 200, the ratio #1 is

determined as not being greater than 20, then at step 206, the confidence value is set to confidence *0.75, after which program execution again continues at step 204. At steps 204, 206, 208, 212 program steps corresponding to steps 198, 200, 202 and 206 respectively are performed with respect to ratio #2 after which program execution continues at step 210. At step 210, a ratio #3 is computed by dividing the ratio #1 by the ratio #2 value after which program execution continues at step 214. At steps 214, 216, 218 and 222, program steps again corresponding to steps 198, 200, 202, 206 are performed with respect to the ratio #3, after which program execution terminates at step 220, at which confidence calculation is effected.

Figure 17 shows an embodiment of a multiple antenna device 200 operating on the principles described with reference to Figures 3(a) and 3(b).

The device 200 has three antennas, 202, 204, 206 of which the antennas 202, 206 are "peak" positioned at inclinations as described with reference to Figures 3(a) and 3(b) and antenna 204 is a "null" antenna having its axis vertical in use of the device. Signal data is captured from the three antennas in any suitable way such as by applying analogue signals to a signal processing unit 208 of the device, as shown. In this, amplifiers 210, 212, 214 separately amplify the signals from the antennas, pass amplified signals through separate low Q bandpass filters 216, 218, 220 from whence they are applied to separate analogue/digital converters 222, 224, 226. Subsequent processing is effected by computer software, in a computational unit 228, having a display 230.

For a null tracing mode, just the null antenna signal from antenna 204 is used. For a peak tracing signal, the signal strength is calculated for each of the two peak antennas 202, 206 and the sum of the signal strengths is used. For tracing and showing the direction to the cable, the phase of the null antenna is compared to the phase of the peak antenna with the strongest signal. It is to be observed here that the analogue signal paths do not need to be designed with unusual attention since the frequency is low, the filtering requirements are easy to achieve and the data acquisition rate may also be low.

In one embodiment, the amplifiers 210, 212, 214 have a gain of 10, the filters 216, 218,

220 are low Q bandpass filters with a Q of 2 and a gain of 2, and the A/D converters 222, 224, 226 are two Crystal semiconductor CS5330A dual channel 18bit A/D's running at 32,000 samples per second. The two A/D's are used to cover the three channels with one input spare. These are provided by way of example and many other embodiments are also possible including automatic and manual gain control, different frequencies and filter characteristics and different sampling rates and sample resolutions. It is also simple to switch between digital/software versions of the filters, compared to analogue versions.

Figure 18 is a flowchart for the software operation of the above embodiment for acquiring the three channels of information. Generally arrays are first cleared and counters also cleared. The system samples at 32,000 samples per second and places results into an array which is eight samples long. At the end of the eight samples, the process begins again with the second row of samples being added to the first. This comprises a multi-scalar array and is used for improving the signal to noise ratio of the data acquisition system. Because the array is eight samples wide and the system is sampling the 8KHz signal at 32 Khz, there will be two complete 8KHz waveforms in the array. The array counter, i, is used to keep track of the place in the array.

An overall counter, c, is used to count the number of passes. For each pass, the signal amplitude doubles but the noise will be random and will increase by the square root of 2. The more passes, the better the signal to noise ratio of the arrays. The embodiment illustrated makes 64 passes which improves the signal to noise ration by $\sqrt{64} = 8 = 18$dB.

In particular, the steps which are executed are as now described.

First, at step 250 the arrays are cleared. At step 252, the counter c is cleared. At step 254, the array counter "i" is cleared. At step 256, the two peak signals and the null signal are read. At step 258, the peak 1, peak 2 and null signals are recomputed by adding the respective signal. At step 260, the counter "i" is incremented. At step 262, it is determined whether the count in counter "i" is equal to 8. If not, steps 256, 258 and 260 are repeated. If so, the counter c is incremented at step 264. At step 266, it is determined whether c is equal to 64. If not, step

254 is executed followed by repetitions of steps 256, 258, 260 until a counter "i" again reaches a count of 8, after which counter c is incremented again at step 264. When counting counter c reaches 64, signal acquisition is completed (step 268).

Once the three channels are acquired, they are processed according to the type of tracing being done. The instrument operation acquires data and then processes it according to the mode selected by the user. This process loops continuously. It is also possible to add additional signal processing and filtering to further improve the results.

Referring to Figure 19, for Null mode tracing, the signal level of the null mode antenna is calculated using a standard RMS process and the result displayed to the user. Here, step 270 comprises the computation of the null RMS value, step 272 comprises displaying the signal level computed at step 270. The latter is followed by an execution complete step 274.

For Peak mode tracing, the signal level of each of the peak antennas is calculated and the sum of the signal strengths is displayed to the user, as shown in Figure 20.

At step 280, peak 1 and peak 2 RMS values are computed. Then, at step 282 the two results are summed together and the summed result displayed at step 284. The process is complete at step 286.

Referring to Figure 21, for Direction to cable mode tracing, the signal level of the Null and Peak antennas is first calculated. The stronger peak signal is then selected. If there is very little peak signal, then the answer may not be reliably calculable. If there is sufficient peak signal then if the null signal it is very low, then the instrument is over the cable and the user can be informed that the instrument is centred over the cable.

Otherwise the phase of the strongest peak signal is compared to the Null antenna signal and if they are in phase then the cable is to the left of the instrument, otherwise it is to the right. The direction corresponds to the antenna orientations.

The phase is compared using a DFT (Discrete Fourier Transform) which is a standard process. The calculation of the RMS value of signals is also a standard process.

These steps are, as illustrated in Figure 21, as follows:

First, at step 290 a null RMS value is computed. At step 292, peak 1 RMS and peak 2 RMS values are computed. At step 294 it is determined whether the peak 1 RMS value is greater than the peak 2 RMS value. If no, a value Peak is set to the peak 2 value, at step 296, if yes the peak value is set to the peak 1 value, at step 299. In either event, it is next determined at step 298 whether the peak value is equal to zero. If yes, it is determined at step 300 that there is insufficient signal to make a direction determination, and the processing moves to step 302 at which the direction to cable mode operation is completed. If the peak value is not zero at step 298, it is then determined whether the null RMS value is equal to zero, at step 304. If yes, processing moves to step 306 at which it is determined that the direction to the cable is "centre" meaning that the device is over the cable. If no, it is determined whether the peak signal is in phase with the null signal, at step 308. If yes, it is determined that the direction to the cable is left of the device, at step 310. If no it is determined that direction is to the right, at step 312. In either event, processing again then moves to step 302. The results at steps 310, 312, 306 and 300 are suitably displayed by the display 230, which may be a visual display device.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The described arrangement has been advanced merely by way of explanation and many modifications may be made thereto without departing from the spirit and scope of the invention which includes every novel feature and combination of novel features herein disclosed.

DATED this 27th day of September, 1999

AEGIS PTY LTD
By its Patent Attorneys
Davies Collison Cave

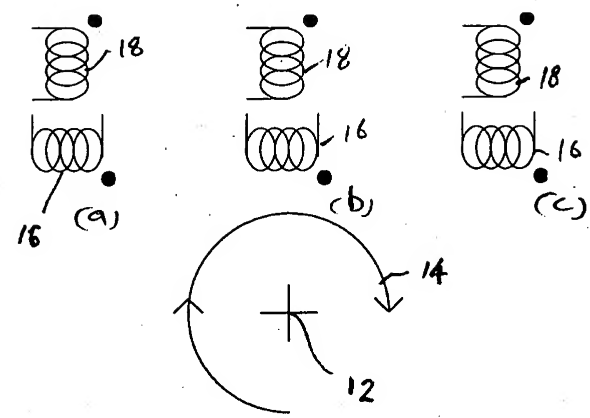
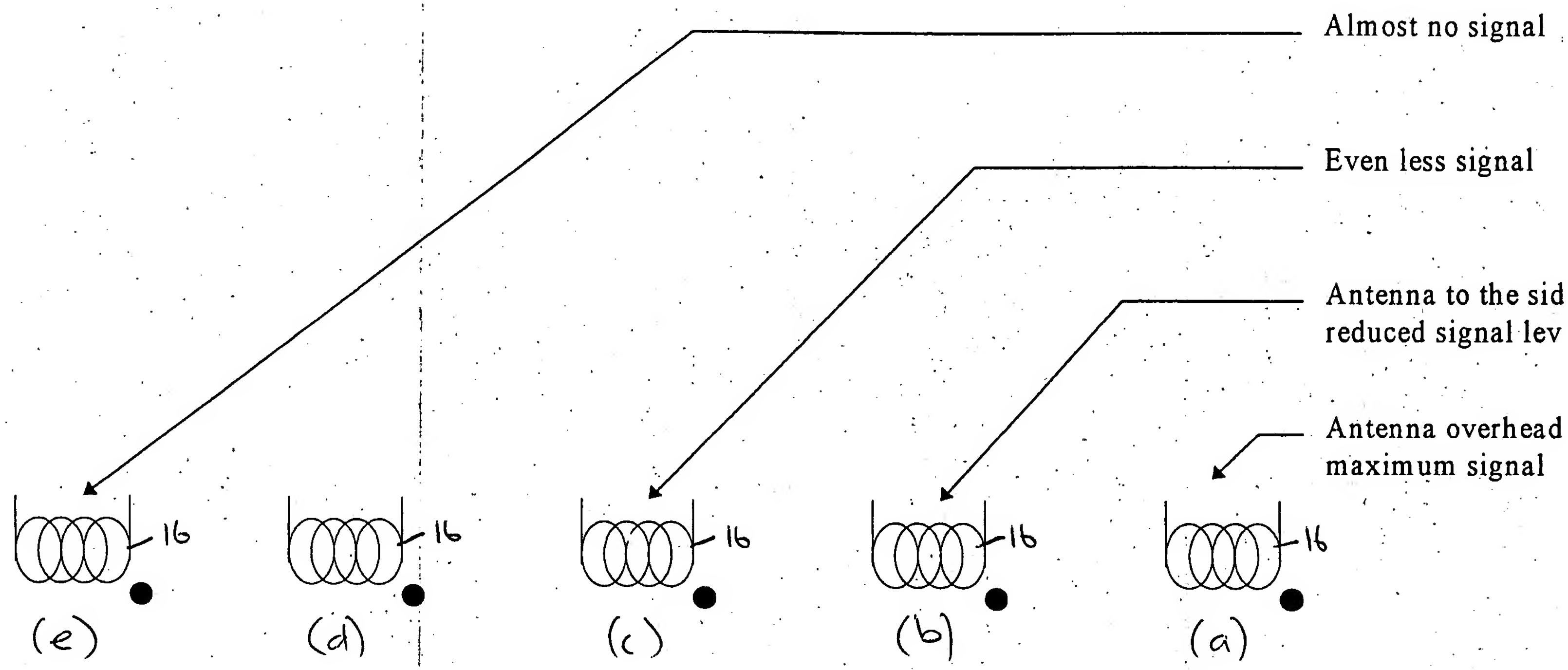


FIGURE 1



As the antenna is moved parallel to the ground and away from the cable, the distance from the antenna to the cable increases and the received signal strength goes down.
In addition, as the angle from the cable to the horizontal antenna becomes shallower, the received signal level also falls off.

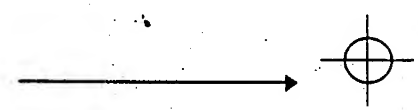


FIGURE 2

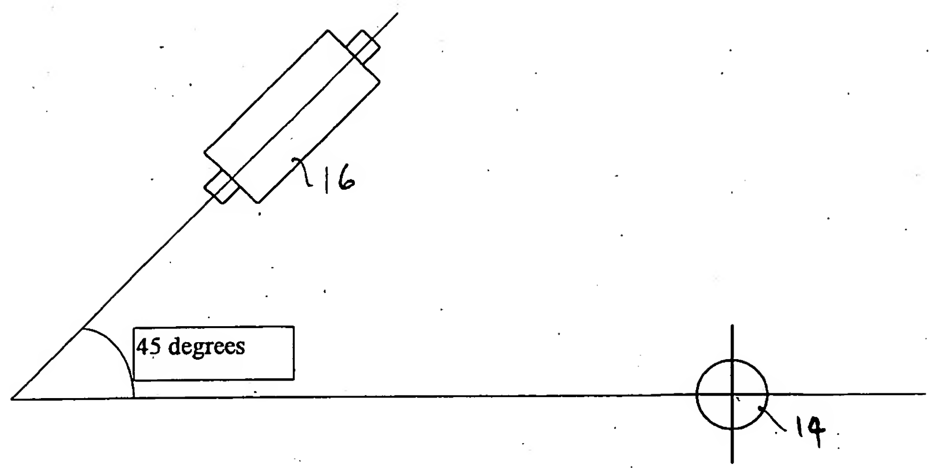


FIGURE 3(a)

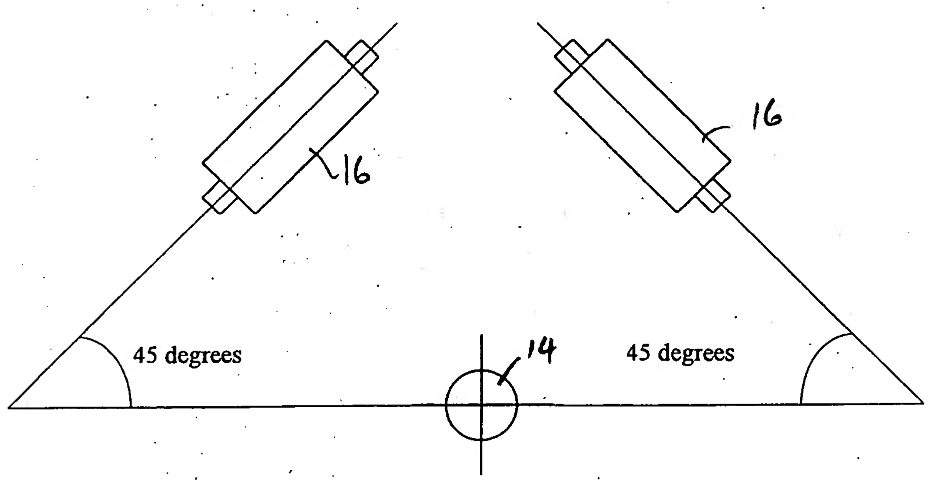


FIGURE 3(b)

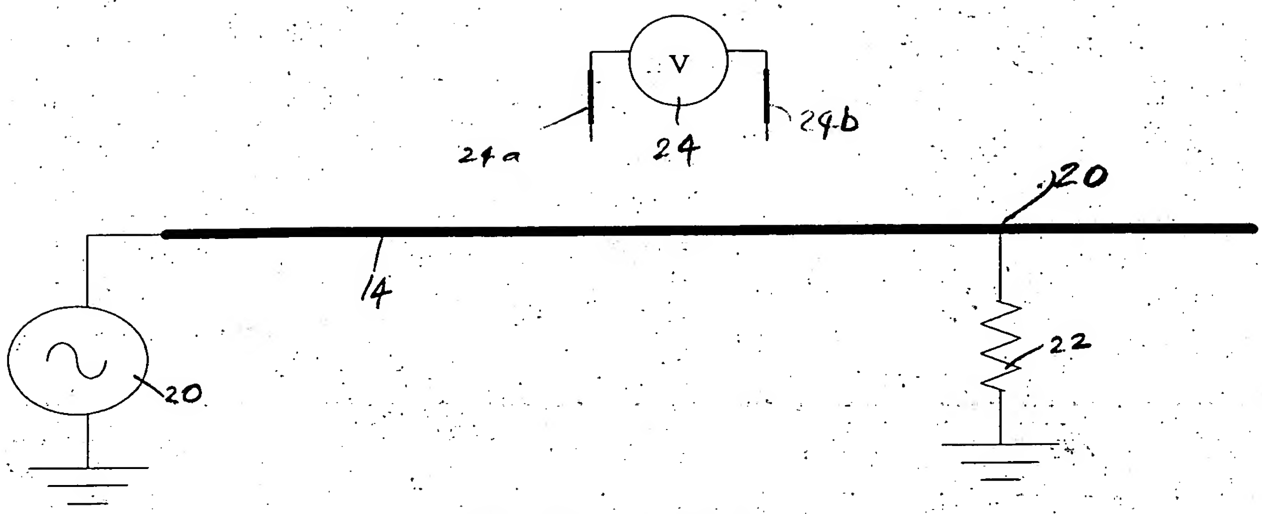


FIGURE 4

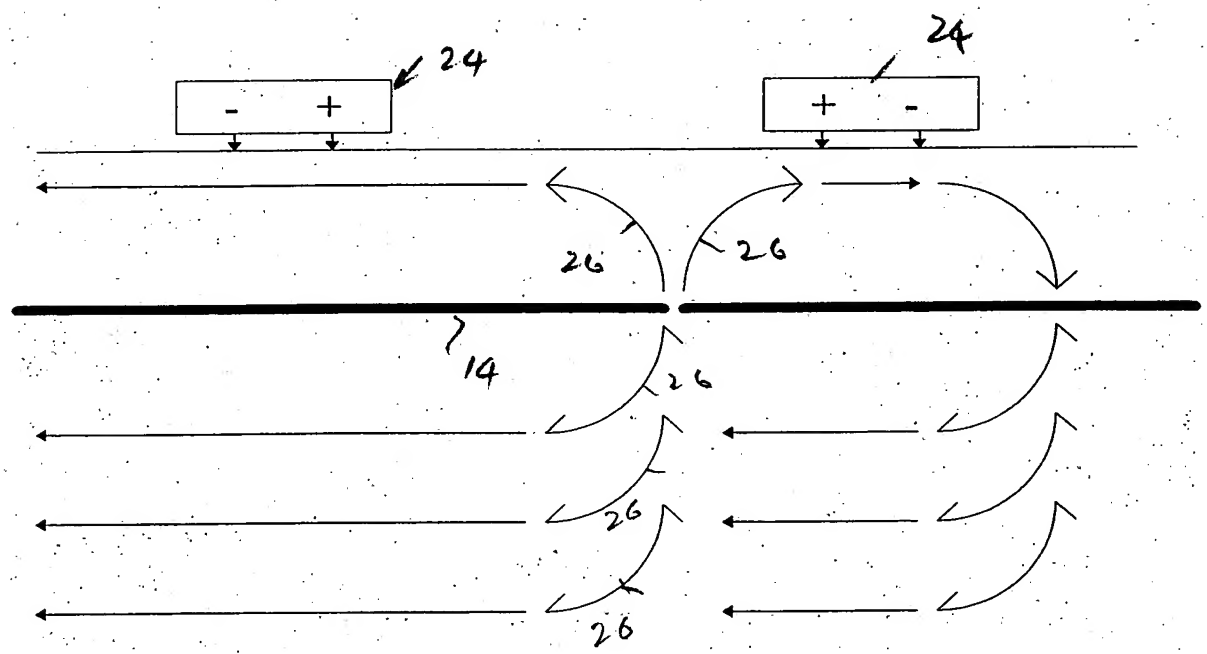


FIGURE 5

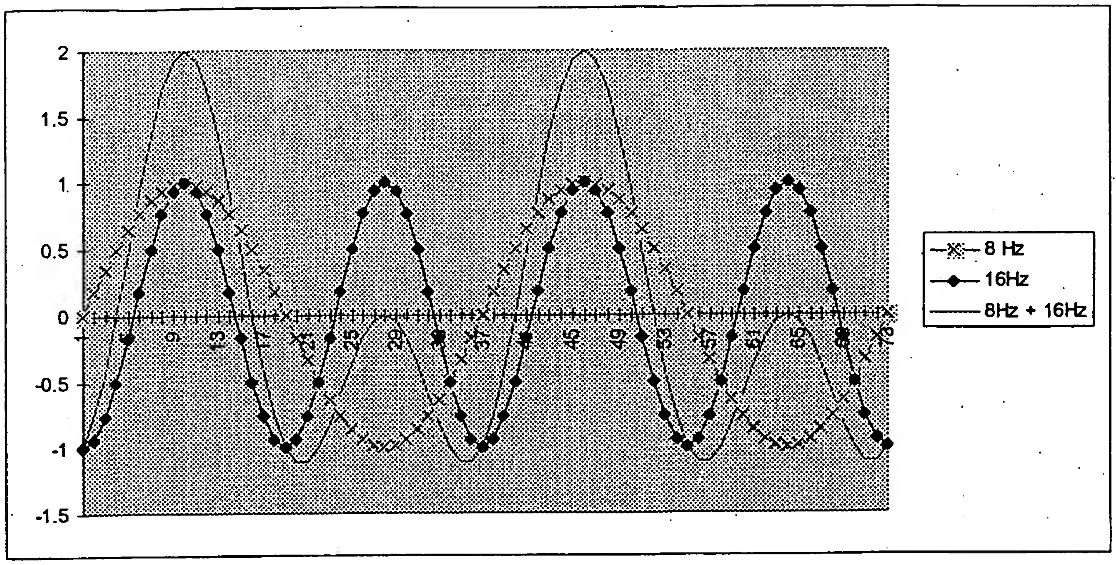


FIGURE 6

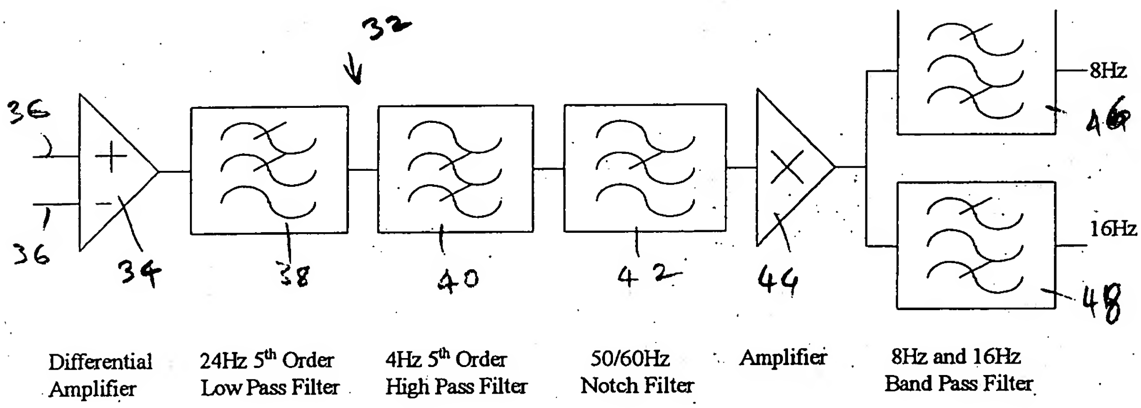


FIGURE 7

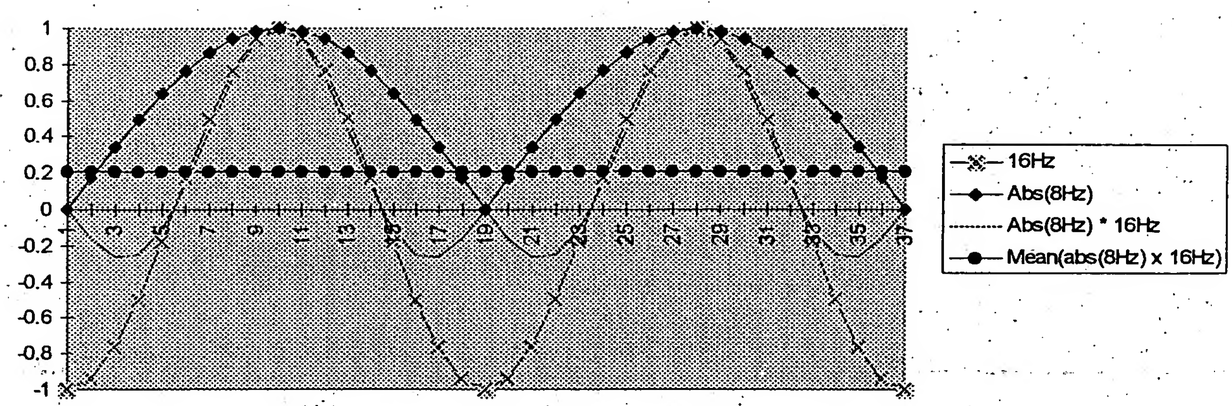


FIGURE 8

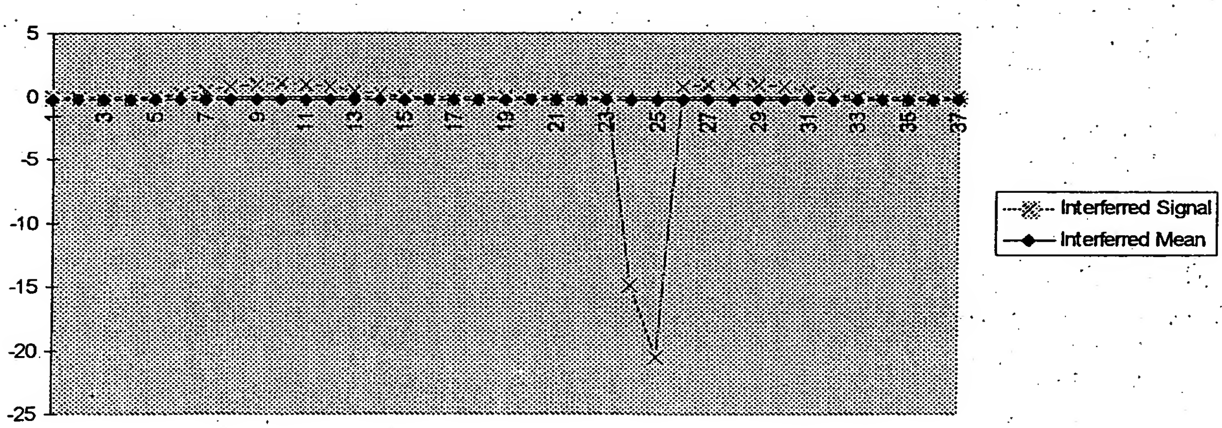


FIGURE 9

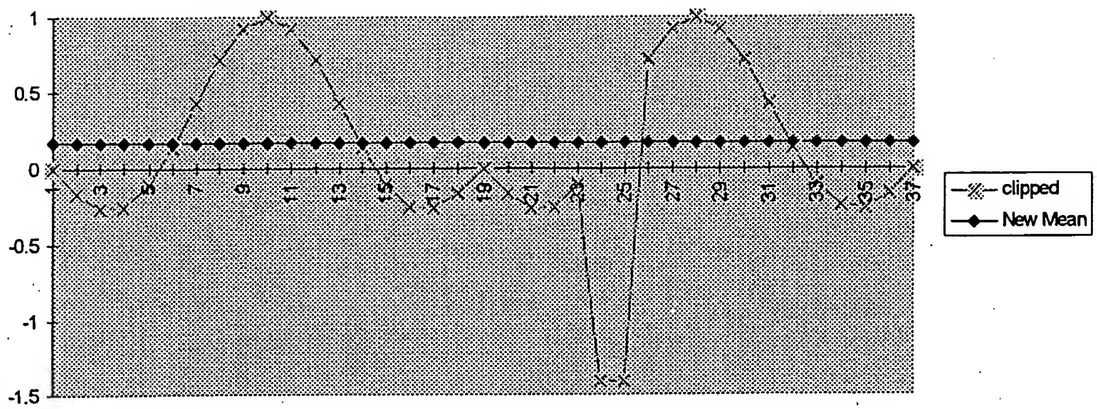


FIGURE 10

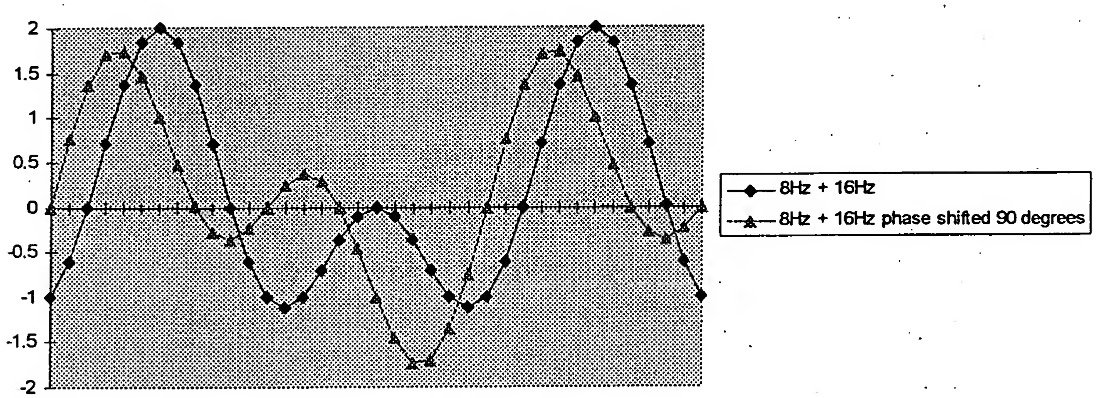


FIGURE 11

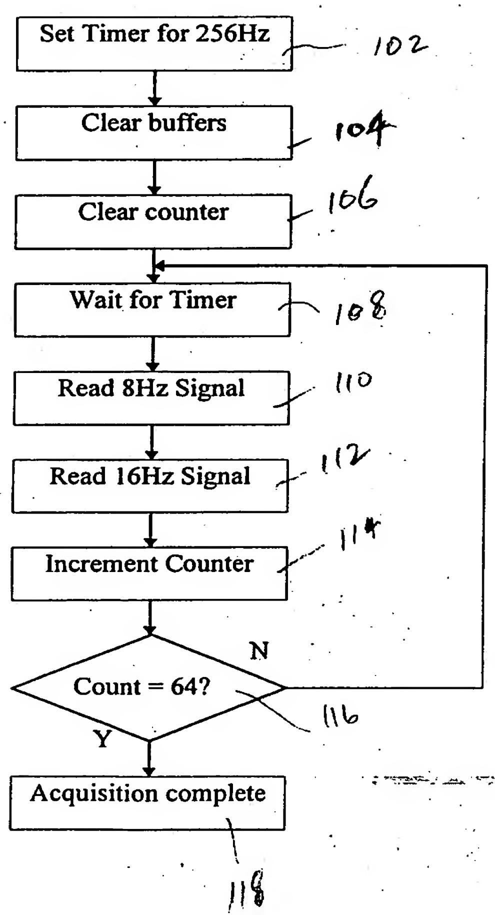

Set Timer for 256Hz
102
Clear buffers
104
Clear counter
106
Wait for Timer
108
Read 8Hz Signal
110
Read 16Hz Signal
112
Increment Counter
114
N
Count = 64?
116
Y
Acquisition complete
118

FIG. 12

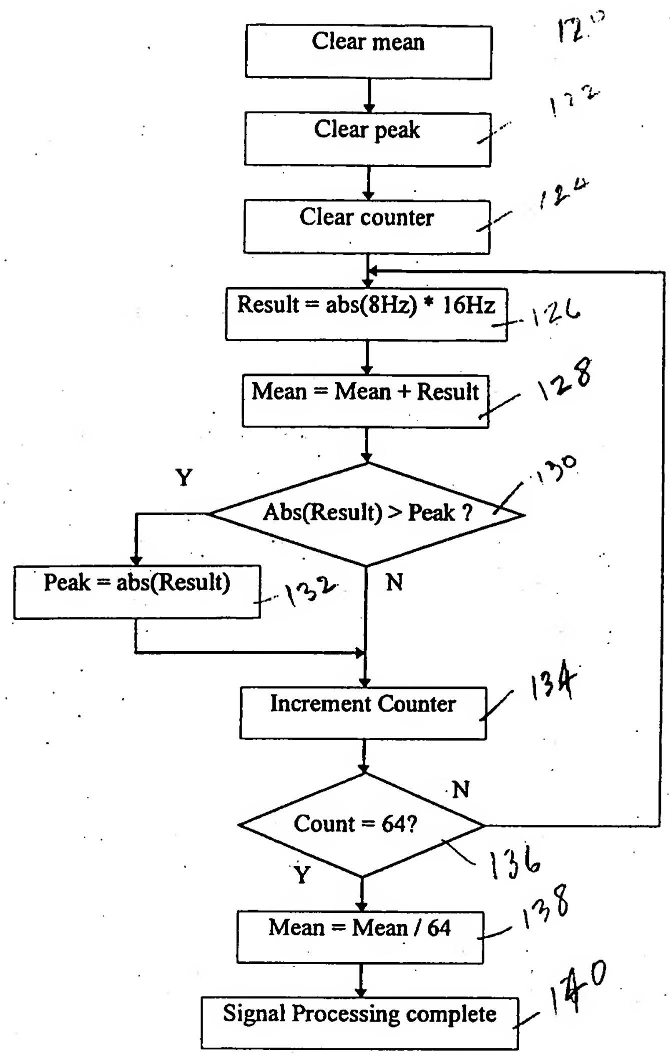
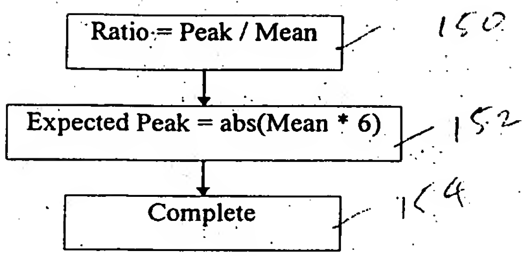
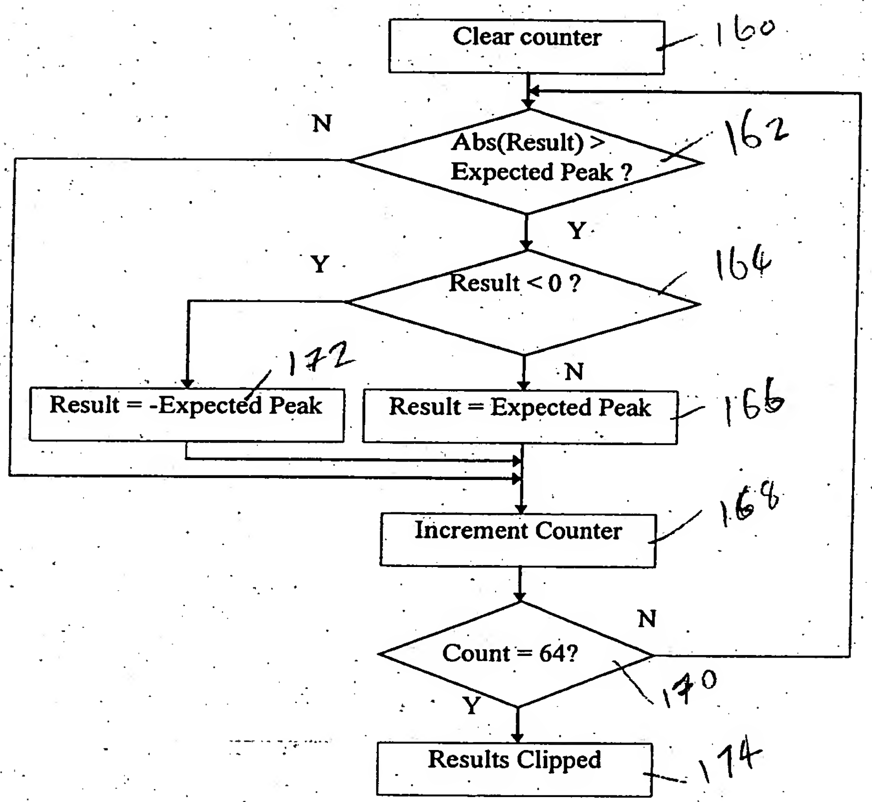

Clear mean
120
Clear peak
122
Clear counter
124
Result = abs(8Hz) * 16Hz
126
Mean = Mean + Result
128
Abs(Result) > Peak ?
130
Y
Peak = abs(Result)
132
N
Increment Counter
134
Count = 64?
N
136
Y
Mean = Mean / 64
138
Signal Processing complete
140

FIG. 13



Ratio = Peak / Mean
150
Expected Peak = abs(Mean * 6)
152
Complete
154

FIG 14



Clear counter
160
N
Abs(Result) > Expected Peak ?
162
Y
Y
Result < 0 ?
164
172
N
Result = -Expected Peak
Result = Expected Peak
166
Increment Counter
168
N
Count = 64?
170
Y
Results Clipped
174

FIG 15

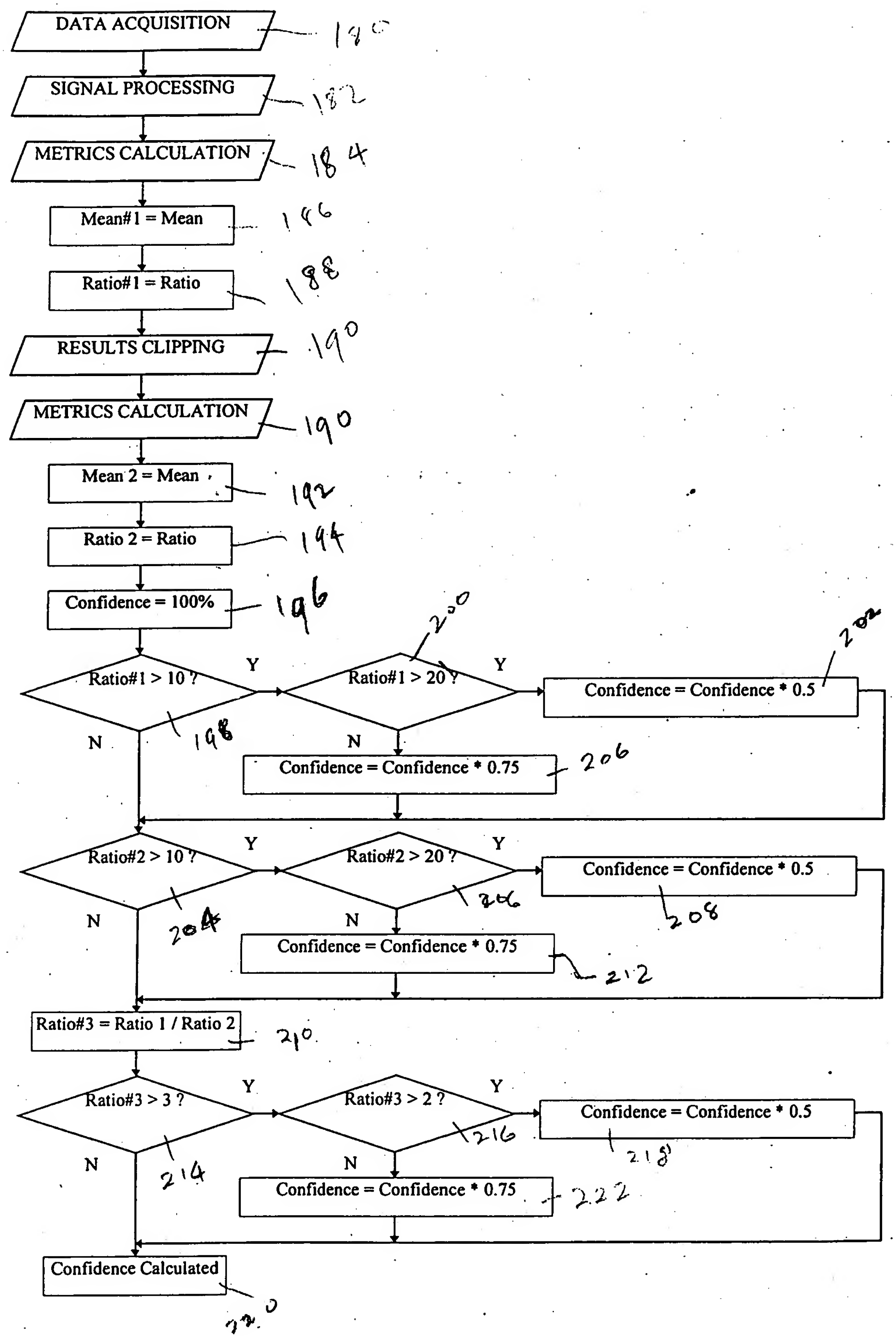

DATA ACQUISITION
180
SIGNAL PROCESSING
182
METRICS CALCULATION
184
Mean#1 = Mean
186
Ratio#1 = Ratio
188
RESULTS CLIPPING
190
METRICS CALCULATION
190
Mean 2 = Mean
192
Ratio 2 = Ratio
194
Confidence = 100%
196
Ratio#1 > 10 ?
198
Y
N
Ratio#1 > 20 ?
200
Y
N
Confidence = Confidence * 0.5
202
Confidence = Confidence * 0.75
206
Ratio#2 > 10 ?
204
Y
N
Ratio#2 > 20 ?
206
Y
N
Confidence = Confidence * 0.5
208
Confidence = Confidence * 0.75
212
Ratio#3 = Ratio 1 / Ratio 2
210
Ratio#3 > 3 ?
214
Y
N
Ratio#3 > 2 ?
216
Y
N
Confidence = Confidence * 0.5
218
Confidence = Confidence * 0.75
222
Confidence Calculated
220

FIG. 16

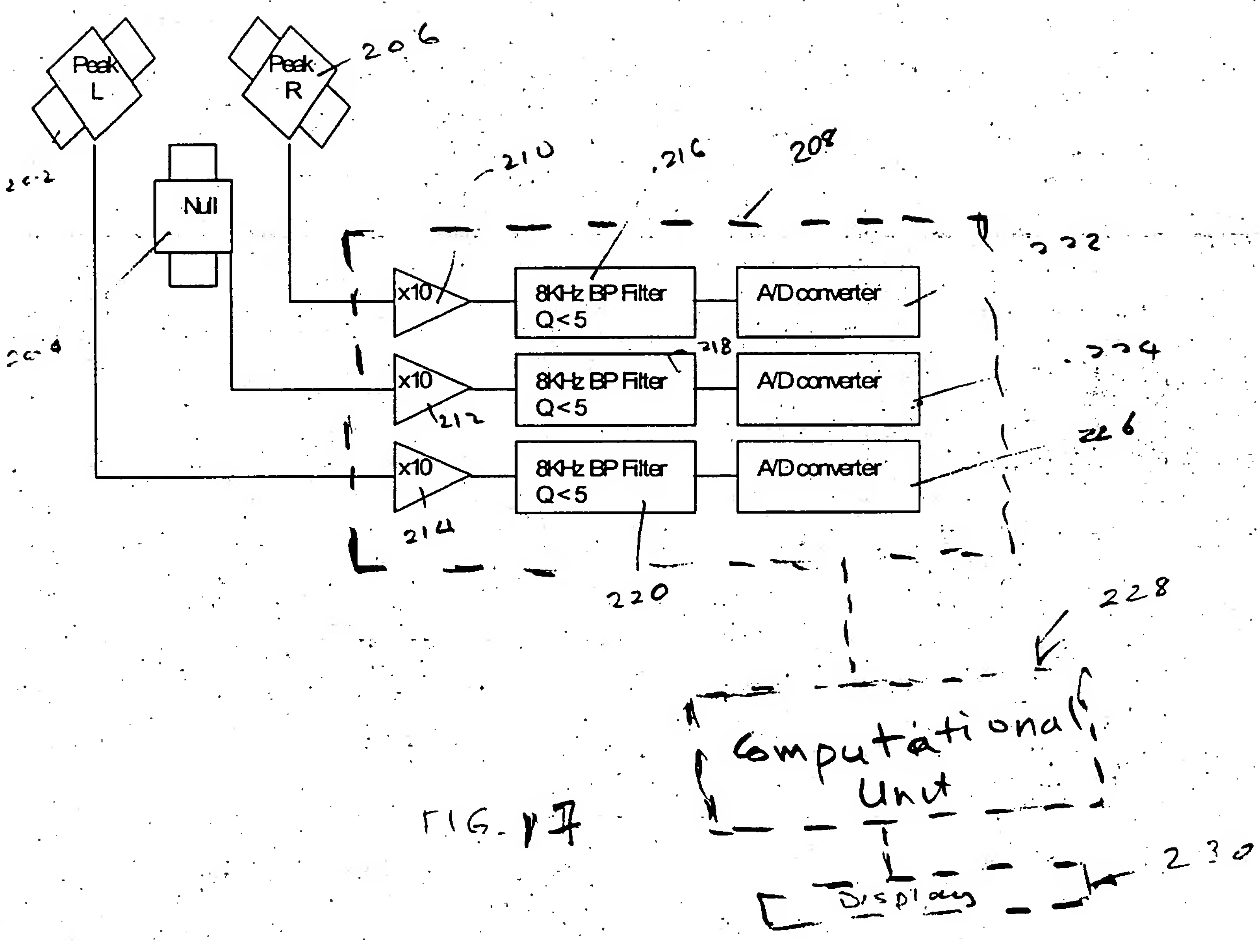
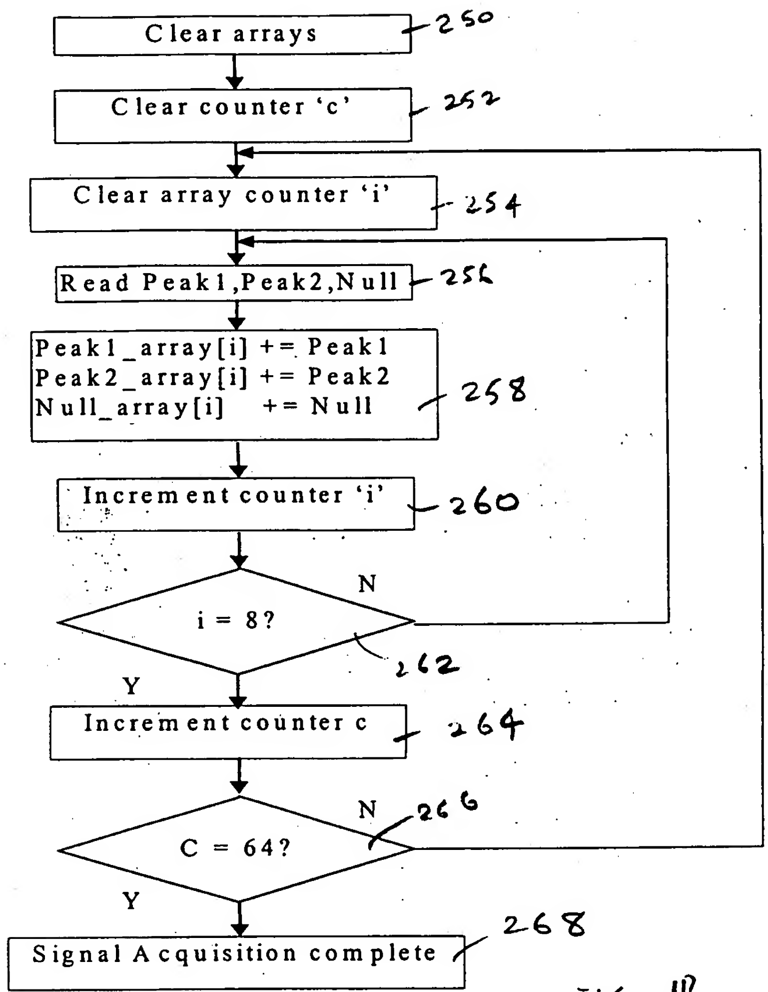

Peak L
Peak R
Null
x10
x10
x10
8KHz BP Filter Q<5
8KHz BP Filter Q<5
8KHz BP Filter Q<5
A/D converter
A/D converter
A/D converter
Computational Unit
Display
206
208
210
212
214
216
218
220
222
224
226
228
230

FIG. 7



Clear arrays
250
Clear counter 'c'
252
Clear array counter 'i'
254
Read Peak1,Peak2,Null
256
Peak1_array[i] += Peak1
Peak2_array[i] += Peak2
Null_array[i] += Null
258
Increment counter 'i'
260
i = 8?
N
Y
262
Increment counter c
264
C = 64?
N
Y
266
Signal Acquisition complete
268

FIG. 18

Null mode tracing

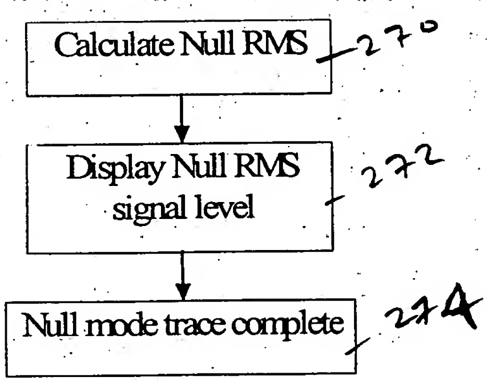


FIG 19

PEAK MODE TRACING

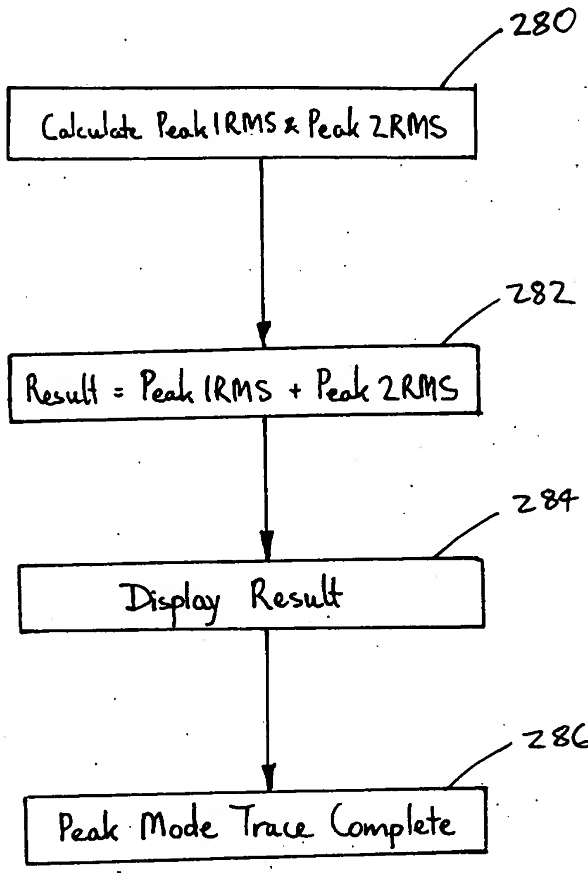


FIG 20

Direction to cable mode tracing

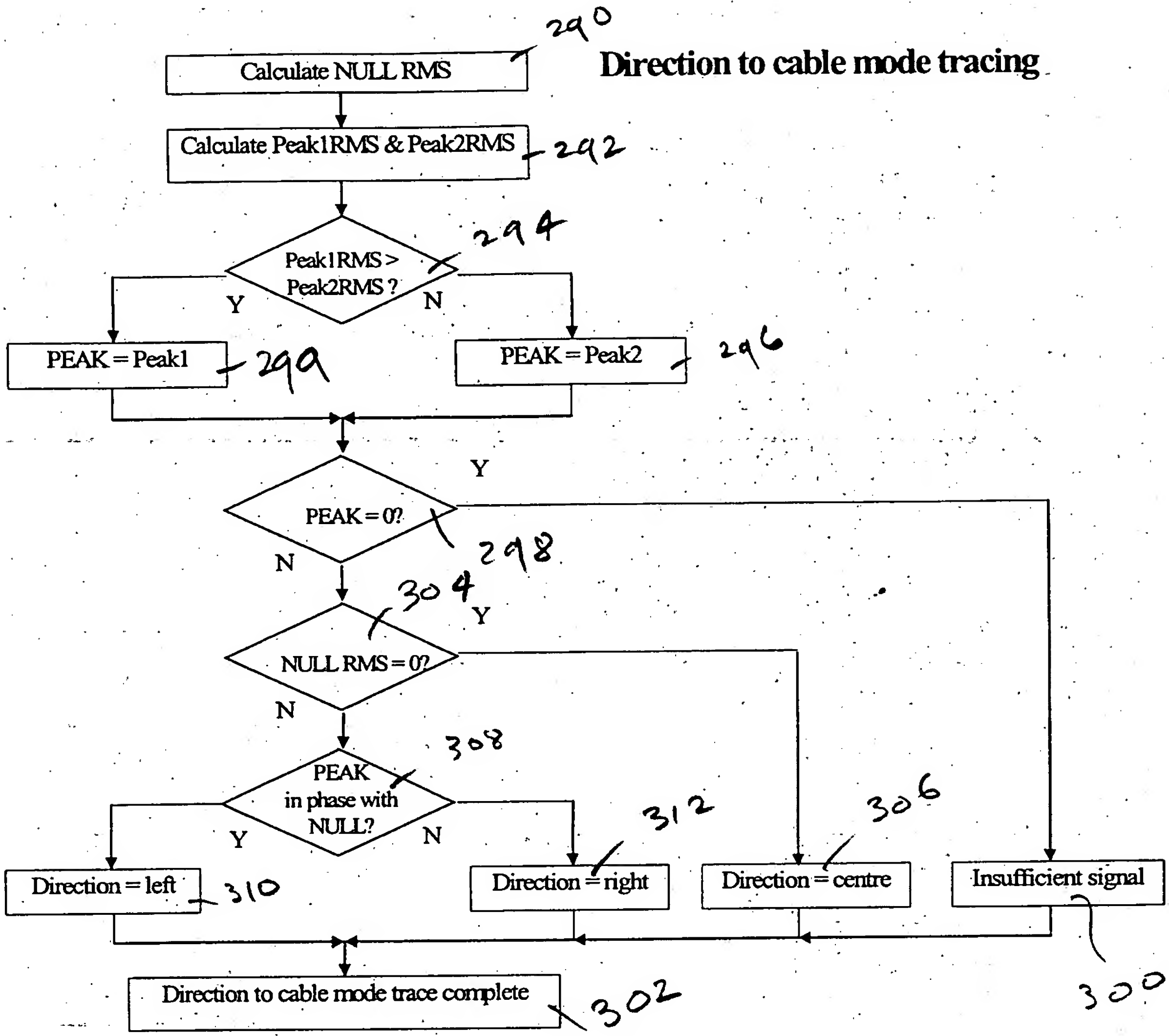


FIG 21